

STATE OF ILLINOIS
DWIGHT H. GREEN, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
FRANK G. THOMPSON, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS — NO. 78

CORRELATION OF DOMESTIC STOKER COMBUSTION
WITH LABORATORY TESTS AND TYPES OF FUELS

I. PRELIMINARY STUDIES

BY

L. C. McCABE, S. KONZO, AND O. W. REES

IN COOPERATION WITH THE UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION



PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

1942

ORGANIZATION

STATE OF ILLINOIS

HON. DWIGHT H. GREEN, *Governor*

DEPARTMENT OF REGISTRATION AND EDUCATION

HON. FRANK G. THOMPSON, *Director*

BOARD OF NATURAL RESOURCES AND CONSERVATION

HON. FRANK G. THOMPSON, *Chairman*

EDSON S. BASTIN, Ph.D., D.Sc., *Geology*

ROGER ADAMS, Ph.D., D.Sc., *Chemistry*

LOUIS R. HOWSON, C.E., *Engineering*

WILLIAM TRELEASE, D.Sc., LL.D., *Biology*

EZRA JACOB KRAUS, Ph.D., D.Sc., *Forestry*

ARTHUR CUTTS WILLARD, D.Engr., LL.D.,

President of the University of Illinois

GEOLOGICAL SURVEY DIVISION

M. M. LEIGHTON, *Chief*

SCIENTIFIC AND TECHNICAL STAFF OF THE
STATE GEOLOGICAL SURVEY DIVISION

100 Natural Resources Building, Urbana

M. M. LEIGHTON, Ph.D., *Chief*
ENID TOWNLEY, M.S., *Assistant to the Chief*
JANE TITCOMB, M.A., *Geological Assistant*

GEOLOGICAL RESOURCES

Coal

G. H. CADY, Ph.D., *Senior Geologist and Head*
L. C. McCABE, Ph.D., *Geologist (on leave)*
R. J. HELFINSTINE, M.S., *Assoc. Mech. Eng.*
JAMES M. SCHOPF, Ph.D., *Asst. Geologist*
J. NORMAN PAYNE, Ph.D., *Asst. Geologist*
CHARLES C. BOLEY, M.S., *Asst. Mining Eng.*
BRYAN PARKS, M.S., *Asst. Geologist*

Industrial Minerals

J. E. LAMAR, B.S., *Geologist and Head*
H. B. WILLMAN, Ph.D., *Assoc. Geologist*
DOUGLAS F. STEVENS, M.E., *Research Associate*
ROBERT M. GROGAN, Ph.D., *Asst. Geologist*
ROBERT R. REYNOLDS, B.S., *Research Assistant*

Oil and Gas

A. H. BELL, Ph.D., *Geologist and Head*
G. V. COHEE, Ph.D., *Asst. Geologist*
FREDERICK SQUIRES, B.S., *Assoc. Petr. Eng.*
CHARLES W. CARTER, Ph.D., *Asst. Geologist*
WILLIAM H. EASTON, Ph.D., *Asst. Geologist*
PAUL G. LUCKHARDT, M.S., *Research Assistant*
WAYNE F. MEENTS, *Research Assistant*

Areal and Engineering Geology

GEORGE E. EKBLAW, Ph.D., *Geologist and Head*
RICHARD F. FISHER, M.S., *Asst. Geologist*

Subsurface Geology

L. E. WORKMAN, M.S., *Geologist and Head*
TRACY GILLETTE, Ph.D., *Asst. Geologist*
ARNOLD C. MASON, B.S., *Asst. Geologist*
KENNETH O. EMERY, Ph.D., *Asst. Geologist*
MERLYN B. BUHLE, M.S., *Asst. Geologist*
FRANK E. TIPPIE, B.S., *Asst. Geologist*
RUTH E. ROTH, B.S., *Research Assistant*

Stratigraphy and Paleontology

J. MARVIN WELLER, Ph.D., *Geologist and Head*
CHALMER L. COOPER, M.S., *Assoc. Geologist*

Petrography

RALPH E. GRIM, Ph.D., *Petrographer*
RICHARDS A. ROWLAND, Ph.D., *Asst. Petrographer*

Physics

R. J. PIERSOL, Ph.D., *Physicist*
B. J. GREENWOOD, B.S., *Mech. Engineer*
DONALD O. HOLLAND, M.S., *Asst. Physicist (on leave)*

Special Staff to Aid in the War Effort

Oil and Gas Resources

EARLE F. TAYLOR, M.S., *Asst. Geologist*
ARNOLD BROKAW, M.S., *Spec. Asst. Geologist*
M. W. PULLEN, JR., M.S., *Spec. Asst. Geologist*
PAUL K. SIMS, M.S., *Spec. Asst. Geologist*
JOHN A. HARRISON, B.S., *Spec. Research Assistant*

GEOCHEMISTRY

FRANK H. REED, Ph.D., *Chief Chemist*
H. W. JACKMAN, M.S.E., *Chem. Eng.*
ROBERTA M. LANGENSTEIN, B.S., *Chemical Assistant*
MELVILLE A. ROGERS, B.S., *Research Assistant*

Coal

G. R. YOHE, Ph.D., *Assoc. Chemist*
MYRON H. WILT, B.S., *Research Assistant*

Industrial Minerals

J. S. MACHIN, Ph.D., *Chemist and Head*
DELBERT L. HANNA, A.M., *Research Assistant*

Fluorspar

G. C. FINGER, Ph.D., *Assoc. Chemist*
EVERETT W. MAYNERT, B.S., *Research Assistant*

X-ray and Spectrography

W. F. BRADLEY, Ph.D., *Assoc. Chemist*

Analytical

O. W. REES, Ph.D., *Chemist and Head*
L. D. McVICKER, B.S., *Asst. Chemist*
P. W. HENLINE, M.S., *Asst. Chemical Engineer*
WILLIAM F. WAGNER, M.S., *Asst. Chemist*
K. F. BURSACK, B.A., *Research Assistant*
MARION LUND DICKMAN, B.S., *Research Assistant*

MINERAL ECONOMICS

W. H. VOSKUIL, Ph.D., *Mineral Economist*
GRACE N. OLIVER, A.B., *Assistant in Mineral Economics*

EDUCATIONAL EXTENSION

DON L. CARROLL, B.S., *Assoc. Geologist*

PUBLICATIONS AND RECORDS

GEORGE E. EKBLAW, Ph.D., *Geologic Editor*
CHALMER L. COOPER, M.S., *Geologic Editor*
DOROTHY E. ROSE, B.S., *Technical Editor*
KATHRYN K. DEDMAN, M.A., *Asst. Technical Editor*
ALMA R. SWEENEY, A.B., *Technical Files Clerk*
PORTIA ALLYN SMITH, *Research Assistant*
MEREDITH M. CALKINS, *Geologic Draftsman*
LESLIE D. VAUGHAN, *Asst. Photographer*
DOLORES THOMAS SIMS, B.A., *Geologic Clerk*

Underground Water Geology

CARL A. BAYS, Ph.D., *Spec. Geologist*
C. LELAND HORBERG, Ph.D., *Spec. Asst. Geologist*
STEWART FOLK, M.S., *Spec. Asst. Geologist*
ERNEST P. DUBOIS, B.S., *Spec. Asst. Geologist*
ROBERT R. STORM, A.B., *Spec. Asst. Geologist*
PAUL HERBERT, JR., B.S., *Spec. Asst. Geologist*
CHARLES G. JOHNSON, A.B., *Spec. Asst. Geologist*

Consultants: *Ceramics*, CULLEN W. PARMELEE, M.S., D.Sc., and RALPH K. HURSH, B.S., University of Illinois;
Pleistocene Invertebrate Paleontology, FRANK COLLINS BAKER, B.S., University of Illinois;
Mechanical Engineering, SEICHI KONZO, M.S., University of Illinois.

Topographic Mapping in Cooperation with the United States Geological Survey.

April 1, 1942

CONTENTS

	PAGE
Introduction	7
Description of the coals studied.....	7
Description of stoker and furnace	11
Laboratory tests	12
British Standards Swelling Index Number.....	12
Agglutinating value	13
Agde Damm test	13
Photographic procedure	14
Results of tests	14
Discussion of results	15
Summary	19


TABLES

1 Analyses of coals used in tests.....	8
2 Comparison of laboratory test values with stoker operation.....	8

ILLUSTRATIONS

FIGURE

1 Block of banded coal from southern Illinois showing fusain, vitrain, and clarain	10
2 Block of banded coal from southern Illinois showing clarain and durain.....	10
3 Diagram of conversion stoker installation.....	12
4 View of the furnace.....	14
5 British swelling index buttons for hand-picked banded ingredients.....	15
6 British swelling index buttons for certain stoker fuels studied.....	16
7 Photographs of stoker fires with various fuels.....	17
8 Photographs of stoker fires with various fuels.....	18
9 Clinkers from vitrain- and clarain-rich fuels.....	19



Digitized by the Internet Archive
in 2012 with funding from
University of Illinois Urbana-Champaign

CORRELATION OF DOMESTIC STOKER COMBUSTION WITH LABORATORY TESTS AND TYPES OF FUELS

I. PRELIMINARY STUDIES

BY

L. C. McCABE,* S. KONZO,† AND O. W. REES‡

INTRODUCTION

IN 1937 THE ILLINOIS GEOLOGICAL SURVEY made exploratory stoker tests of coals from Franklin County, Illinois,¹ which demonstrated that in these coals concentration of vitrain causes excessive swelling and coke-tree formation whereas clarain is more free-burning and has considerably less tendency to form coke trees. The behavior of these two types of coal or mixtures of them could be demonstrated in stokers but no exact tests short of combustion were available for determining their suitability. The need for such test methods to evaluate coals for stoker use is generally recognized.

It was with this need in mind that the exploratory stoker tests were continued and were supported by a variety of laboratory procedures in 1939 and 1940 by the Illinois Geological Survey in cooperation with the Department of Mechanical Engineering of the University of Illinois. These tests and the supporting laboratory data are described in this report.

The coals were collected and prepared under Dr. McCabe's supervision. Dr. Rees directed the routine analyses and the special laboratory tests. The combustion tests were made in a domestic underfeed stoker in the Warm Air Research Residence at the University of Illinois under Professor Konzo's supervision.

The writers gratefully acknowledge the helpful suggestions of Dr. G. H. Cady, Head of the Coal Division of the Survey, and of Professor A. P. Kratz of the Engineering Experiment Station of the University of Illinois.

DESCRIPTION OF THE COALS STUDIED

The investigation was primarily concerned with Illinois coals and the differences inherent in them. However in order to inquire more adequately into the problems met in burning bituminous coals in stokers and better to test the laboratory procedures, a few coals that originated outside the State were included. The origin and the proximate and ultimate analyses of the coals used in the tests are given in table 1.

The banded character of coals, in southern Illinois particularly, has an important bearing on their preparation and utilization. The three most common components, fusain, vitrain, and clarain, are illustrated in figure 1. The fourth, durain or splint (fig. 2), occurs infrequently in No. 6 coal in Franklin County and more abundantly in the splint coals of the Appalachian fields.

Fusain, the most friable of the four components, breaks down during the mining and preparation until the greater part of it will pass a 100-mesh screen.^{2, 3} Little of it is found, therefore, in well prepared stoker coals.

Vitrain does not break as easily as fusain but it is much more friable than clarain. Clarain is closely knit and

* Geologist, Illinois Geological Survey.

† Special Research Associate Professor of Mechanical Engineering, University of Illinois.

‡ Chemist, Illinois Geological Survey.

¹ McCabe, L. C., Illinois coals; Constitution important with reference to their utilization: *Mech. Engr.*, p. 217, March 1933; Illinois Geol. Survey Cir. 26, 1938.

² Parks, B. C., and McCabe, L. C. Fusain content of fine sizes of Illinois coal: *Trans. Illinois Acad. Sci.* vol. 33, no. 2, Dec. 1940; Illinois Geol. Survey Cir. 68, 1940.

³ Thiessen, Gilbert, Fusain content of coal dust from an Illinois dedusting plant: *Am. Inst. Mining and Met. Engr. Tech. Pub.* 664, 1936.

TABLE 1.—ANALYSES OF

Location	Coal bed	Sample	Laboratory number	Condition*	Moisture	Volatile matter	Fixed carbon
Illinois							
Franklin Co.....	6	A	C-2204	1	5.7	42.8	46.6
				2		45.4	49.4
Franklin Co.....	6	E	C-2212	1	7.9	35.0	48.1
				2		38.0	52.2
Franklin Co.....	6	B	C-1988	1	6.5	34.4	52.2
				2		36.8	55.9
St. Clair Co.....	6	C	C-2133	1	9.2	41.8	43.2
				2		46.1	47.5
St. Clair Co.....	6	D	C-2134	1	10.2	36.9	42.2
				2		41.1	47.0
Gallatin Co.....	5	G	C-2132	1	3.6	36.6	48.0
				2		38.0	49.8
West Virginia							
Raleigh Co.....	Eagle	F	C-2252	1	1.5	29.9	63.4
				2		30.3	64.4
Raleigh Co.....	Pocahontas 3	H	C-2135	1	0.8	18.3	75.2
				2		18.4	75.9

TABLE 2.—COMPARISON OF LABORATORY

Coking tendency observed in the fuel bed		British Standard Swelling Index No.		Agglutinating Value (15:1)		Softening Temp. Agde Damm	
Sample ¹	Indication	Sample ¹	Value	Sample	Value	Sample ¹	Value
A	None	A	3	A	2.5	G	324°C
B	None	B	3	F	2.0 ²	C	330
C	None	C	4	E	4.1	D	331
D	Slight	D	4½	H	6.3	E	348
E	Slight	E	4½	C	6.6	F	353
F	Positive	F	5	G	8.0	A	361
G	Very positive	G	7½	D	8.1	B	366
H	Very positive	H	9			H	412

* 1. As received; 2. Moisture-free.

¹ A—Franklin County, Ill. Durain-rich No. 6
B—Franklin County, Ill. Clarain-rich No. 6
C—St. Clair County, Ill. Top coal No. 6
D—St. Clair County, Ill. Bottom coal No. 6
E—Franklin County, Ill. Vitrain-rich No. 6
F—Raleigh County, West Virginia. Eagle seam
G—Gallatin County, Ill. No. 5
H—Raleigh County, West Virginia. Pocahontas No. 3
² Silicon carbide to coal ratio, 20 to 1

COALS USED IN TESTS

Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	B. t. u.	Description
4.9	1.37	5.99	73.66	1.58	12.50	13,260	Durain-rich
5.2	1.46	5.69	78.13	1.68	7.84	14,064	Vitrain-rich
9.0	1.75	5.43	67.29	1.49	15.00	11,941	
9.8	1.90	4.94	73.08	1.62	8.64	12,971	Clarain-rich
6.9	1.09					12,532	
7.3	1.16					13,405	Top coal
5.8	3.03	5.94	67.05	1.68	16.48	12,212	
6.4	3.34	5.43	73.84	1.85	9.14	13,449	Bottom coal
10.7	3.71	5.53	61.77	1.19	17.06	11,131	
11.9	4.13	4.89	68.79	1.32	8.91	12,395	2x1 in. screen
11.8	3.85	5.19	70.02	1.42	7.76	12,719	
12.2	3.99	4.97	72.60	1.48	4.76	13,189	Lump
5.2	0.59	5.14	81.57	1.54	5.96	14,468	
5.3	0.60	5.06	82.81	1.57	4.68	14,688	Lump
5.7	0.77	4.59	84.24	1.59	3.13	14,576	
5.7	0.78	4.54	84.92	1.60	2.43	14,693	

TEST VALUES WITH STOKER OPERATION

Decomposition Temp. Agde Damm		Setting Temp. Agde Damm		Initial Contraction Interval. Agde Damm		Plastic Interval Agde Damm	
Sample ¹	Value	Sample ¹	Value	Sample ¹	Value	Sample ¹	Value
G	384°C	D	414°C	H	38°C	H	58°C
C	392	C	416	B	49	B	67
D	401	B	433	A	58	A	73
F	415	F	434	C	62	F	81
B	415	E	436	F	62	D	83
E	417	A	438	G	64	C	86
A	419	G	>444	E	69	E	88
H	450	H	470	D	70	G	>120



FIG. 1.—Block of banded coal from southern Illinois showing fusain (F), vitrain (V), and clarain (C).



FIG. 2.—Block of banded coal from southern Illinois showing clarain (C), and durain (D).

withstands breaking when mechanically handled. Durain is the toughest and most resistant component. The following excerpt from a recent U. S. Bureau of Mines publication⁴ describes the energy consumed in pulverizing the four coal constituents:

“Contrary to general belief the ash-bearing constituents are not always most resistant to crushing, as was shown in tests of coal constituents, that is vitrain, clarain, durain, and fusain—from the Southern Illinois field. The net power consumed in crushing the constituents from minus 20-mesh to minus 150-mesh, with their ash content is given in the following table:

Coal Constituent	Fusain	Vitrain	Clarain	Durain
Net horse power—hours per ton of minus 150-mesh product...	1.8	3.8	5.1	13.6
Ash, percent.....	15.6	2.2	8.3	5.2

It is shown that the durain, the hardest constituent, contains less ash than the clarain, although comparison of the values for fusain with any of the others is even more startling. It has been recognized that fusain is the most easily crushed constituent, in spite of its relatively large percentage of ash.”

Study of production has shown that the breakage characteristics of the constituents in commercial coal are reflected by the energy necessary to pulverize them. Both vitrain and clarain can be found in lump sizes, and the parting surfaces may have a thin layer of fusain on them. Most of the fusain will have been broken off, however, and can be found in the screenings; or if the coals are dedusted, it will be in the deduster dust. In wet-washing most of the fusain is carried to the settling pond. For this reason, it is not considered in the stoker tests.

The 3- by 2-inch egg contains some of the smaller vitrain bands, but for the most part is clarain. The No. 2 nut (2- by 1¼-inch) is still richer in clarain. The

⁴ Fieldner, A. C., and Rice, W. E., Annual report of research and technologic work on coal, fiscal year 1940: U. S. Bur. Mines I. C. 7143, pp. 23-24, 1940.

No. 3 nut ($1\frac{1}{4}$ - by $\frac{3}{4}$ -inch) of well-banded coals has eight to ten percent more vitrain than the coal bed from which it is mined. This concentration prevails down to the 100- or 200-mesh size, but fusain is the predominant component in smaller sizes.

In general, 800 to 1000 pounds of coal were prepared for the stoker tests, and about 50 pounds were riffled from this sample for the proximate and ultimate analyses and special tests. The high-vitrain sample (70 percent vitrain, 30 percent clarain) from Franklin County, Illinois, was taken directly from the $7/16$ -inch by 10-mesh stoker coal-loading chute at the mine. The high-clarain sample (84 percent clarain, 16 percent vitrain) from the same mine was prepared by crushing 3- by 2-inch egg-coal to stoker size. The durain sample was prepared by crushing to stoker size 6- by 3-inch egg-coal from which the other constituents had been removed.

In the Belleville district near Darmstadt in St. Clair County the upper two feet of No. 6 coal is a bright micro-banded clarain with silky luster, low ash and high volatile content, and a relatively high B.t.u. value. The lower four feet of the bed consists of alternating bands of clarain, vitrain, and fusain. The ash of the bottom coal is higher and the volatile matter and B.t.u. values are considerably lower than in the top coal (table 1). When coals of this type are poorly prepared, lack of uniformity due to segregation and other factors may cause difficulties in stoker operation.

Because the rocks of Gallatin County have been folded and faulted, the No. 5 coal bed of that region is of higher rank than the same bed in Saline County. Although clarain predominates in this bed, the coal has been so increased in rank that it is all strongly swelling.

The Eagle Seam and Pocahontas coals of Raleigh County, West Virginia, are high-rank coals not represented in Illinois but were tested in order to have a wider range of coals in the stoker and laboratory tests. Run-of-mine was crushed in both instances to make the stoker coals used in the tests.

DESCRIPTION OF STOKER AND FURNACE

A complete description of the Warm Air Research Residence and the forced warm-air heating system, together with the automatic control system used to operate the stoker and the circulating fan, has been reported in two papers.^{5, 6} The heating plant consisted of a warm-air furnace used in connection with the forced-air heating system. The furnace was of the cast-iron circulator-radiator type having a 27-inch firepot and 23-inch grate. As shown in figure 3, the stoker was of the underfeed type, and the coal was delivered from the hopper to the retort by means of a rotating screw. The retort was located in the center of the hearth. Both the rate of fuel input and the rate at which air was supplied to the tuyeres could be independently regulated. No cut-off damper was provided in the air tube to prevent air being drawn through the blower and into the fuel bed during the off periods of the stoker. The overfire damper in the firing door was left open prior to the photographing of the fuel bed. The pyrex plate glass door which was placed in position just prior to the photographic study was fitted loosely on the furnace front to give a total overfire air opening approximately equivalent to that provided by the regular firing door and the overfire damper opening. A balanced check damper was installed in the clean-out of the chimney and was regulated to maintain a constant draft of approximately 0.05 inches of water in the smoke pipe.

After a new batch of coal had been added to the hopper the plant was allowed to operate intermittently under thermostatic control for two or three days, at the end of which time the fuel bed had assumed the characteristics of the coal under test. During this preliminary period of adjustment approximately 300 to 600 pounds of coal were

⁵ Kratz, A. P., Konzo, S., and Engdahl, R. B., Performance of stoker-fired and hand-fired warm-air furnaces in the research residence: A.S.H.V.E. Journal section, Heating, Piping, and Air Conditioning, pp. 732-742, Nov. 1933.

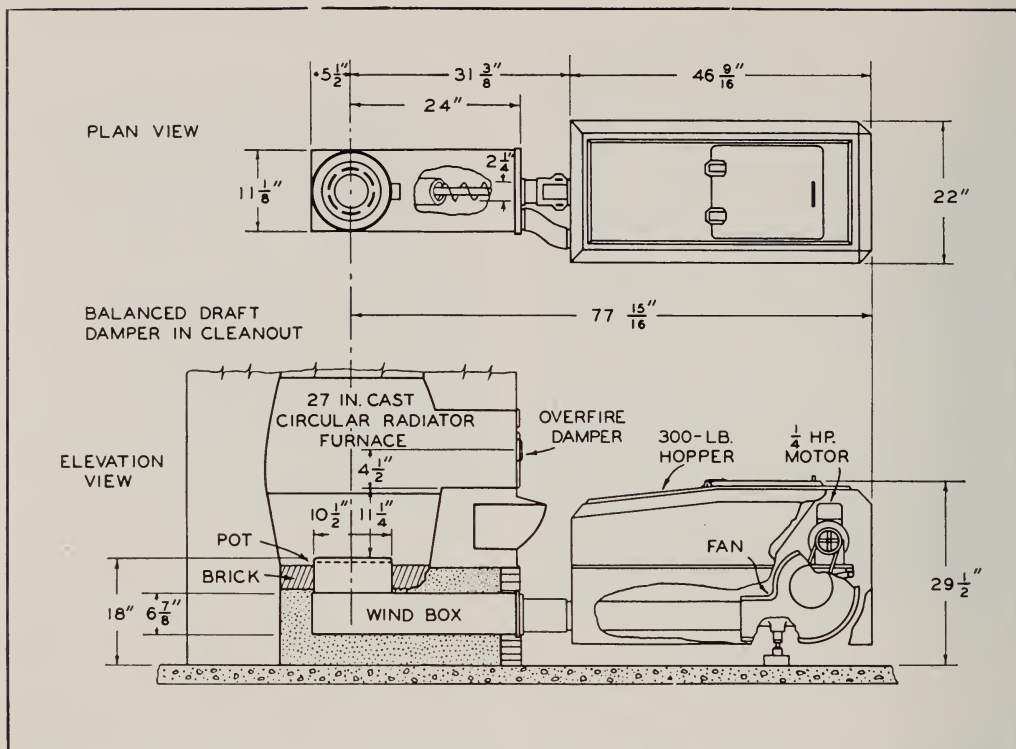


Fig. 3.—Diagram of conversion stoker installation in furnace in research residence.

burned. The feed rate maintained during the tests was about 26 pounds per hour. The setting for air-rate to the stoker was maintained the same in all cases. The resulting burning rate⁶ varied somewhat depending upon the coal used, but averaged about 13 pounds per hour. It is possible that the rate at which air is supplied to the fuel bed may affect the coking characteristics of the fuel. Hence the results obtained in this preliminary survey may not be entirely representative of the coking action of the coal over a wide range of air rates and feed rates. It would be advisable in any later studies to investigate this phase of the problem.

⁶ Kratz, A. P., and Konzo, S., Performance of a stoker-fired warm-air furnace as affected by burning rate and feed rate: A.S.H.V.E. Journal section, Heating, Piping, and Air Conditioning, pp. 55-60, January 1940.

LABORATORY TESTS

Proximate and ultimate analyses were made on all samples tested according to standard procedures of the American Society for Testing Materials.⁷

BRITISH STANDARDS SWELLING INDEX NUMBER

Swelling index numbers were determined according to the British Standard method⁸ with the following modifications:

1. Instead of the B.S. 72-mesh test sieve specified by the British Standard method for preparation of the test sample a No. 60 U. S. Standard sieve was used.

⁷ Standard methods of laboratory sampling and analysis of coal and coke: A.S.T.M. designation, D271-37.

⁸ British standard method for the crucible swelling test for coal: British Standards Institution pub. no. 804, 1938.

2. In place of the "Teclu" burner a Fisher high temperature usual style burner with grid top was used. By placing a thermocouple inside the crucible and experimentally adjusting the gas flow to the burner, it was possible to establish conditions of proper temperature and proper rate of heat rise. Natural gas of approximately 1000 B.t.u. calorific value was used.

3. Transite pipe class F was used for the draught shield. This pipe was $4\frac{3}{4}$ inches outside diameter and 4 inches inside diameter. It was cut according to the specifications given in the standard method.

4. The crucibles which were used were glazed vitreosil of the following specifications:

External height26 to 26.6 mm
External diameter at top..40 to 41.5 mm
Internal diameter at base..13 to 14 mm
Capacity17 to 17.5 ml
Weight11 to 12 gms.

5. Silica triangles which are supplied as standard items by most chemical apparatus supply houses were used. Those used in this work were about 63.5 mm in length of side with a diameter of inscribed circle of about 31.75 mm.

Briefly the test consists of heating one-gram portions of coal in the standard crucibles at a specified rate of temperature rise until all the volatile matter has been expelled. The buttons are then removed from the crucibles and compared to standard outlines to which have been assigned numbers from 1 to 9. The average of four such tests is the value reported.

AGGLUTINATING VALUE

Agglutinating value determinations were made according to the "Proposed Method of Test for Agglutinating Value of Coal" as published by the American Society for Testing Materials.⁹ A ratio of 15 silicon carbide to 1 coal was used for all samples with the exception of sample F' where a ratio of 20 to 1 was used.

The apparatus used for crushing test buttons was designed and built in this laboratory.

This method is a laboratory test for obtaining information on the coking and caking properties of coal. It is an approximate measure of the material in coal which becomes plastic under the influence of heat. Briefly the procedure consists of mixing coal with an inert material such as silicon carbide, coking the mixture as in a volatile matter determination and determining the compression strength of the buttons so formed.

AGGE DAMM TEST

The apparatus used in this test was similar to that described in U. S. Bureau of Mines Bulletin 344.¹⁰ This apparatus was further described by Thiessen.¹¹ It consists essentially of a cylindrical copper block three inches in diameter and seven inches long which is fitted into a specially built electric furnace. Two $\frac{1}{2}$ -inch holes are provided in this copper block for the small sample tubes. The apparatus is so arranged that a one-pound rod rests on one sample while a micrometer distance gauge is mounted on the top of the rod in such a way as to register contraction or expansion of the sample. The other sample is allowed to expand and contract freely. Thermocouples are provided for temperature readings. In the tests the samples of coal which have been compressed in the sample tubes under a weight of 5.8 kilograms are heated at a specified rate, and distance gauge and temperature readings are recorded. When plotted, these data show the initial softening temperature, the decomposition temperature, the solidification temperature, and the plastic interval.

⁹ Proposed method of test for agglutinating value of coal (proposed draft): A.S.T.M. Standards on Coal and Coke, p. 95, 1938.

¹⁰ Fieldner, A. C., Davis, J. D., Thiessen, R., Kester, E. B., and Selvig, W. A., Methods and apparatus used in determining the gas-, coke-, and by-product-making properties of American coals: U. S. Bur. Mines Bull. 344, p. 16, 1931.

¹¹ Thiessen, G., Coke from Illinois coals: Illinois Geol. Survey Bull. 64, Appendix B, page 223, 1937.



FIG. 4.—View of the furnace showing pyrex door, lamps, and camera in position for photographing fuel bed.

PHOTOGRAPHIC PROCEDURE

A pyrex glass door replaced the firing door while the fuel beds were being photographed (fig. 4) so that the normal operation of the stoker was not affected. The combustion chamber was illuminated by two No. 2 Photoflood lamps in reflectors; this lighting was necessary to properly distinguish between coke and clinker masses.

A Weston meter was used to determine the proper exposure of the film. Exposures were made at 16 frames per second with a 15 mm, F 2.7 lens. Four hundred feet of 16 mm, Type A, Kodachrome film was used in making the moving pictures of the fuel beds of the eight coals. This was supplemented by 300 feet of film showing the coals, special laboratory equipment, and titles. Photo-

graphs of the fuel beds were taken at intervals as follows:

- Fuel bed prior to stoker operation
- Start of stoker operation
- Fuel bed after five minutes of stoker operation
- Beginning of off-period
- Photograph of clinkers.

RESULTS OF TESTS

Analyses of the coals used in this study are given in table 1. Results of the special tests are given in table 2, and British Standards Swelling Index buttons are shown in figures 5 and 6. Photographs of stoker fires for the fuels studied are shown in figures 7 and 8, and clinkers from vitrain- and clarain-rich fuels are shown in figure 9.

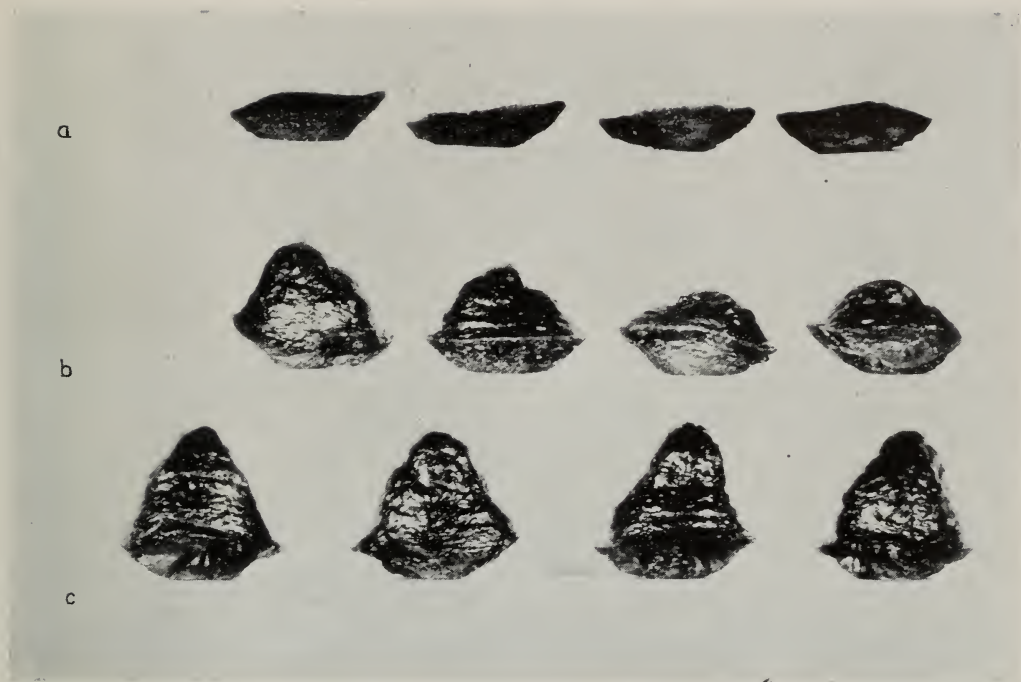


FIG. 5.—British swelling index buttons for hand-picked banded ingredients.
a. durain; b. clarain; c. vitrain.

DISCUSSION OF RESULTS

The correlations attempted in this study were (1) correlation of laboratory tests with combustion behavior in the underfeed stoker, and (2) correlation of types of coal with combustion behavior. There appeared to be no correlation between agglutinating and Agde Damm values and the formation of coke in the fire bed, which was the principal combustion behavior characteristic observed. However the authors believe that results of these tests may be correlated with combustion characteristics other than coke formation. A study of such correlations and of correlations with other chemical tests is now in progress. Correlations of British Standards Swelling Index values and types of coal with combustion behavior were possible and the discussion deals mainly with these correlations.

Figure 5 illustrates the swelling buttons obtained from hand-picked samples of durain, clarain, and vitrain from a mine in Franklin County, Illinois. The durain sample (figure 5a) showed no

tendency to swell and is therefore assigned a swelling index of one. Clarain (figure 5b) and vitrain (figure 5c) had swelling indices of 3 and 5 respectively.

Large samples having the purity of small hand-picked samples could not be readily prepared. While the 800- to 1000-pound samples were not composed entirely of a single ingredient the concentration obtained by the preparation methods described earlier in this report is sufficient to illustrate the characteristics of the predominant ingredient in the sample.

The egg-coal crushed to make the durain-rich stoker fuel contained some vitrain and clarain. The standard coke button for this fuel is given the number 3 in table 2. The predominant durain influence on the swelling is brought out by comparing these buttons (figure 6a) with the hand-picked durain and clarain buttons (figures 5a and 5b). British Standards Swelling Index buttons for coals A, F, G and H are shown in figures 6a, b, c, d. Figures 7a and 7b are enlargements from moving picture film of

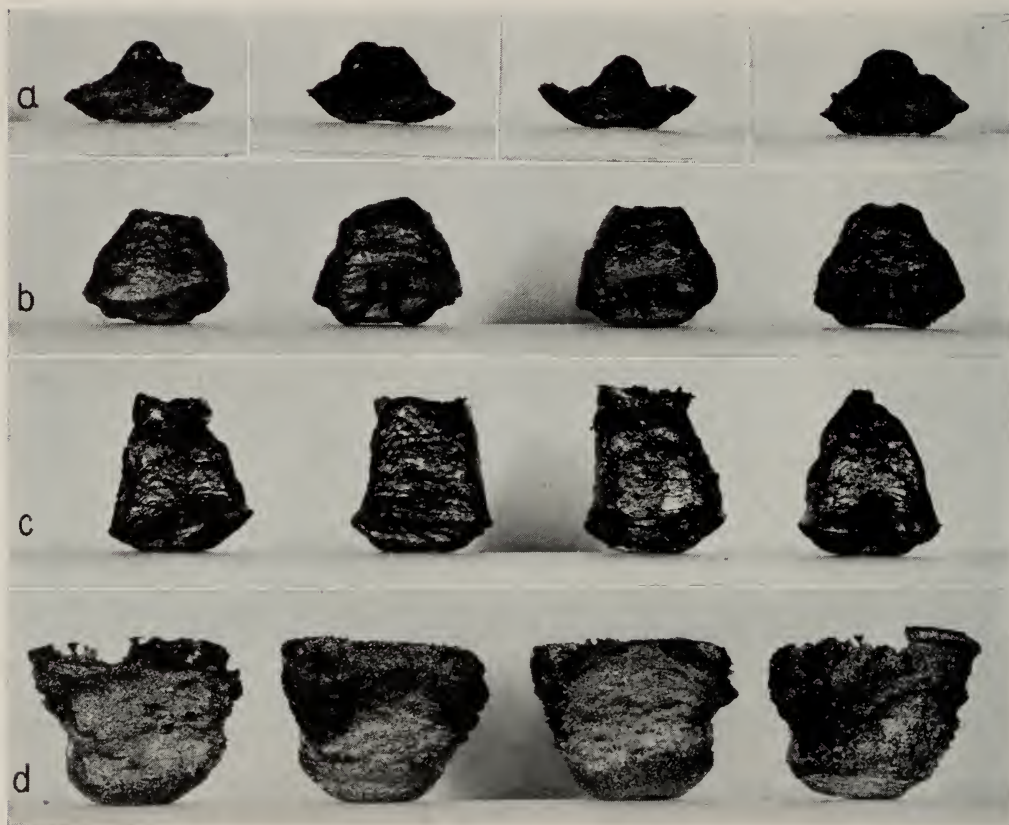


FIG. 6.—British swelling index buttons for certain stoker fuels studied.

a. Durain-rich stoker fuel; b. Eagle Seam, West Virginia, stoker fuel;
c. Gallatin County No. 5 stoker fuel; d. Pocahontas stoker fuel.

two stages in burning of the durain-rich coal. The stoker is just coming on in figure 7a and the fuel bed is readily seen. Figure 7b, after five minutes of stoker operation, illustrates the freedom from coking and the uniformity of the fuel bed. There is somewhat more smoke at the beginning of the off-period with durain than with the clarain or vitrain.

The clarain-rich fuel ("B", table 2) had a swelling index of 3 as did the hand-picked sample (figure 5b). Figure 7c illustrates the beginning of stoker operation and 7d shows the open nature of the fuel bed after five minutes in the on-period.

The vitrain-rich sample ("E", table 2) has a swelling index of $4\frac{1}{2}$ as compared with an index of 5 for the carefully hand-picked sample, which indi-

cates the presence of a small amount of durain or clarain. However, figure 7e illustrates the tendency of the vitrain to form coke in the off-period. Figure 7f illustrates the behavior of this friable coke tree after five minutes of stoker operation. Only in mild weather when the stoker operates infrequently might any difficulty be encountered with a vitrain-rich coal of this type.

The top coal of the Belleville District of St. Clair County has a swelling index of 4; the bottom coal has a swelling index of $4\frac{1}{2}$ (table 2, samples C and D). There is practically no coke formation apparent when the top coal is burned, and only a slight tendency to form coke in the bottom coal (figures 8a and 8b). The difference in swelling tendency is attributed to the presence of a greater amount of vitrain in the bottom coal. At

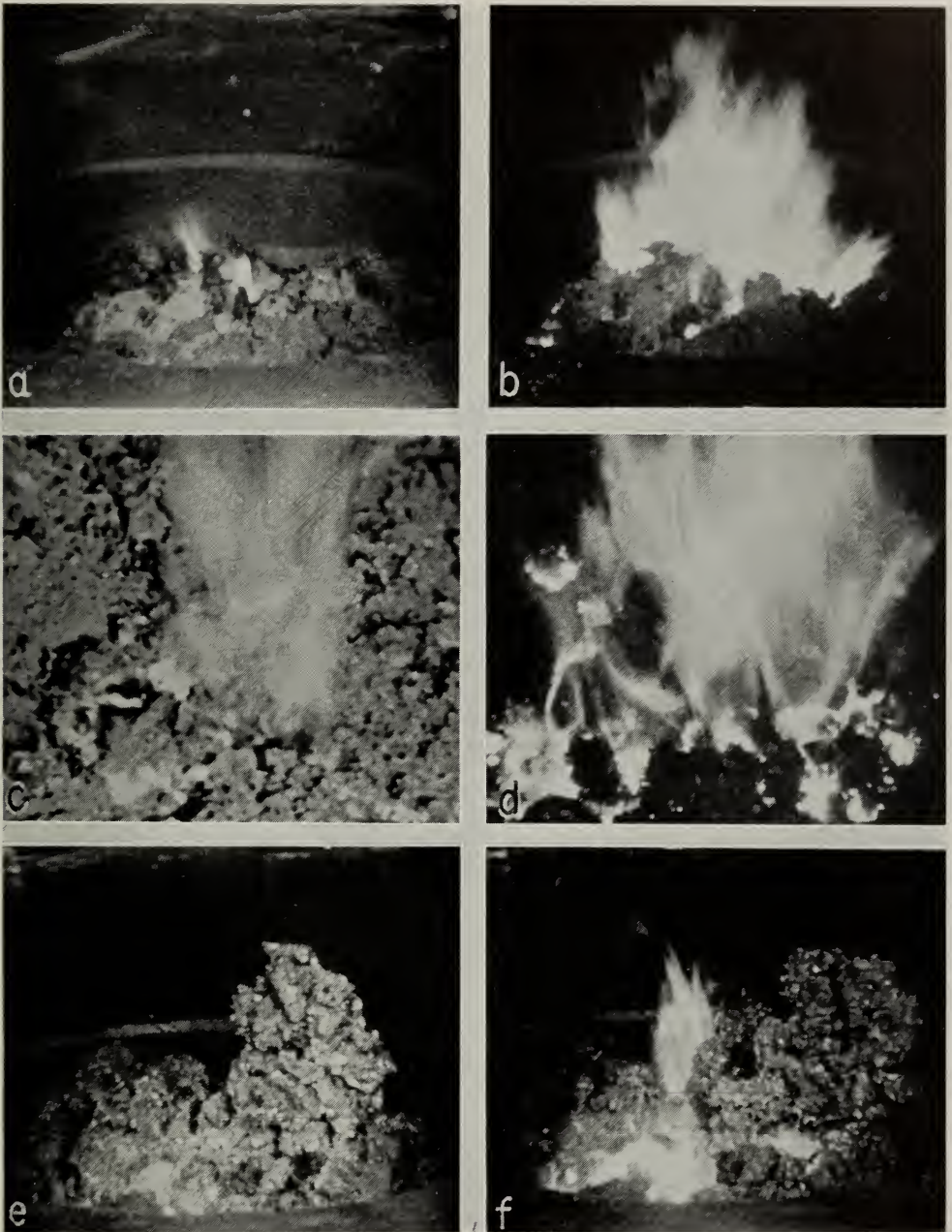


FIG. 7.—Photographs of stoker fires with fuels as follows:

- a. Stoker fire, durain-rich fuel, stoker just turned on
- b. Stoker fire, durain-rich fuel, after 5 minutes of operation
- c. Stoker fire, clarain-rich fuel, stoker just turned on
- d. Stoker fire, clarain-rich fuel, after 5 minutes of operation
- e. Stoker fire, vitrain-rich fuel, stoker just turned on
- f. Stoker fire, vitrain-rich fuel, after 5 minutes of operation

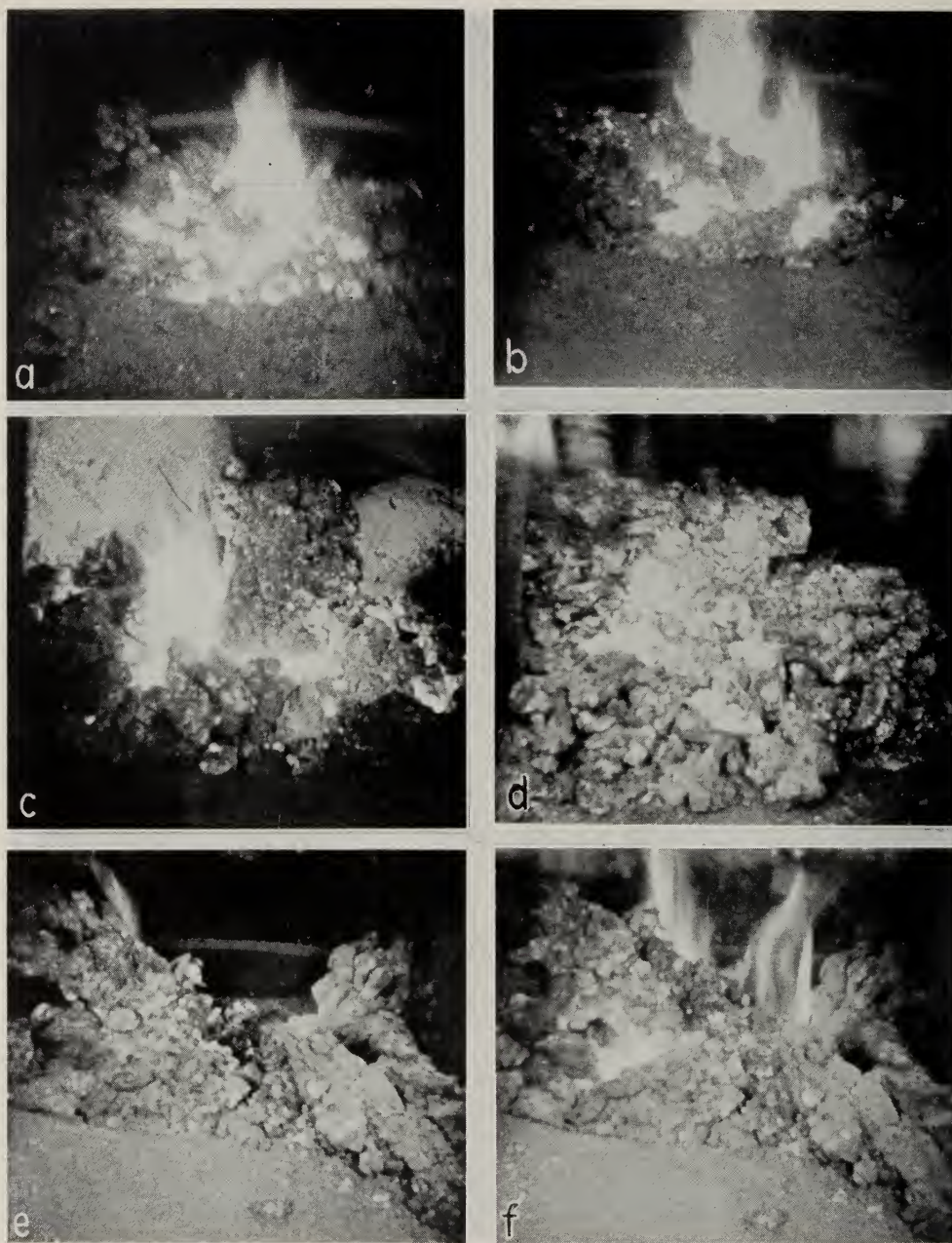


FIG. 8.—Photographs of stoker fires with fuels as follows:

- a. Stoker fire, top bench St. Clair County No. 6 coal, after 5 minutes of operation
- b. Stoker fire, lower bench St. Clair County No. 6 coal, after 5 minutes of operation
- c. Stoker fire, Eagle Seam, West Virginia coal, after 5 minutes of operation
- d. Stoker fire, Gallatin County No. 5 coal, after 5 minutes of operation
- e. Stoker fire, Pocahontas coal, stoker just turned on
- f. Stoker fire, Pocahontas coal, after 5 minutes of operation

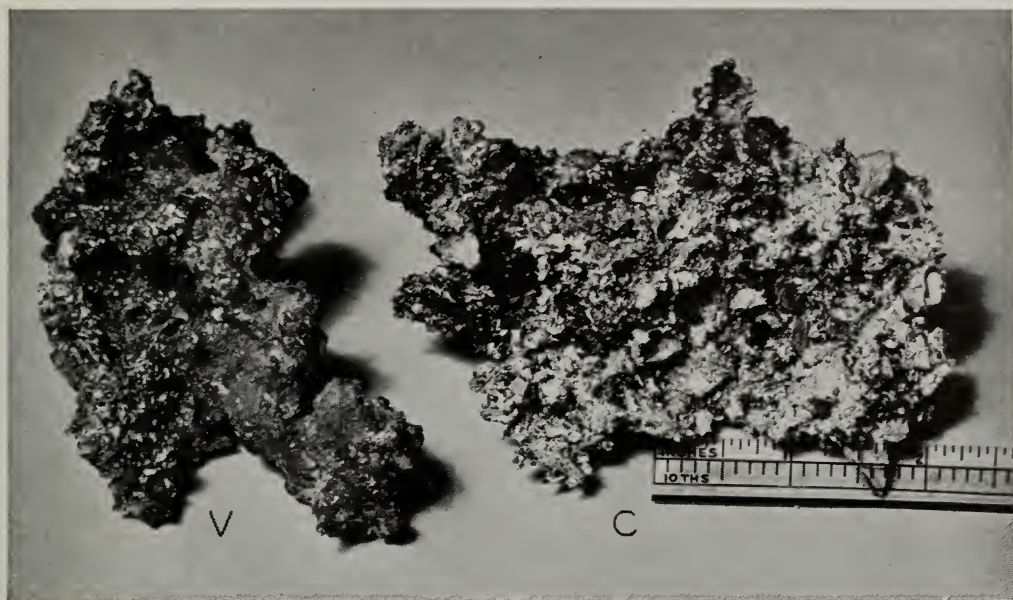


FIG. 9.—Clinkers from vitrain- and clarain-rich fuels.

the beginning of the off-period the top coal has a considerably greater tendency to smoke than the bottom coal. This is explained, in part at least, by the higher volatile content of the top coal (46.1 and 41.1 per cent respectively on the dry basis).

The Eagle Seam coal (Raleigh County, West Virginia) is assigned a swelling number of 5. A peculiarity of this coal is that after heat is removed from the crucible the apexes of the buttons collapse. This may have some bearing on the behavior of this coal during combustion. In assigning a swelling number this apex is restored, however. Figure 8c shows the condition of the fuel bed after the stoker had operated for five minutes. Part of the coke ring formed on the hearth appears in the foreground of the figure and a coke tree appears in the center. The coke formed in the stoker was dense but in spite of this the response to combustion was not unsatisfactory.

The Gallatin County (No. 5) coal, with a swelling index of $7\frac{1}{2}$, had a tendency to form flat masses of coke in the furnace rather than coke trees (fig. 8d). Such coke masses ignited less readily

than the original coal when the stoker came on after being off for some time.

The Pocahontas fuel bed is shown in figure 8e and f. Figure e shows the appearance with the stoker just coming on and f shows the appearance after operation for five minutes. Reference to this figure and table 2 shows that there is considerable coke formation with this fuel (swelling index number 9) under the conditions used for this study.

Figure 9 shows a vitrain clinker as compared to a clarain clinker. The vitrain clinker appears to be denser and harder than the clarain clinker.

SUMMARY

This paper is a preliminary attempt to correlate behavior of various types of coal in an underfeed stoker with laboratory tests for the few samples studied under one specific set of conditions.

The tests substantiate earlier findings in regard to the importance of physical composition of coal, that is, types of fuel, as related to combustion behavior.

No correlations between agglutinating value and Agde Damm plasticity tests and coke formation were apparent.

Correlation between British Standards Swelling Index values and coke formation in the stoker fire was apparent. This is in accord with the findings of Sherman.¹² On the basis of these studies it appears that coals with B. S. I. numbers below 4½ or 5 do not form appreciable masses of coke in the fuel bed whereas coals with B. S. I. numbers of 5 or above may form large amounts of coke.

Although coals of high-vitrain content tend to form more coke than those of high-clarain and high-durain content, this difference is not as striking in the present tests as might be predicted from

the swelling index numbers of the hand-picked constituents of the Franklin County coal.

Laboratory tests described in this report measure more or less specific characteristics of coal. On the other hand, behavior of coal in an underfeed stoker is influenced simultaneously by many physical and chemical properties. The influence of certain properties may mask that of others. Studies are now in progress to clarify some of these relationships.

¹² Sherman, Ralph A., The evaluation of coal for use in domestic stokers: Univ. Illinois Eng. Experiment Sta. Cir. ser. 39, pp. 39-57, 1939.